GIS Based Multi-Criteria Decision Making for Flood Vulnerability Index Assessment

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***Abstract*—Over the past few years, Malaysia suffers severe flooding, especially in the States of Kelantan, Pahang and Kedah. One of the most important part of flood risk management is to evaluate the vulnerability to floods. This paper is intended to highlight the potential integrated of Geographic Information System (GIS) and Multi Criteria Decision Making (MCDM) to develop Flood Vulnerability Index (FVI) map. For this study, four different vulnerability components, i.e. social, economic, infrastructure and physical were considered. The criteria for each of components were determined based on expert opinions and literature review. For this study only Rank Sum and Analytical Hierarchy Process (AHP) techniques in MCDM were used. Based on these MCDM techniques, FVI models were developed and FVI maps were generated. Findings have shown that the most vulnerable areas are mainly located along the rivers and Kota Setar was found to be the most vulnerable district within the study area. Slight differences in terms of the vulnerable area ranking can be observed when different MCDM techniques were used. Identifying areas with high flood vulnerability may guide the decision makers and planners towards a better way of dealing with floods by societies.**

***Index Terms*—Geographical Information System (GIS); Multi Criteria Decision Making (MCDM); Flood Vulnerability Index (FVI); Analytical Hierarchy Process (AHP).**

I. INTRODUCTION

Improper land use development and heavy rainfall are considered as the major causes of flooding in Malaysia. During recent years, there is a lot of record on the loss of life and damage caused by flood disaster [1]. Report from the Department of Irrigation and Drainage of Malaysia uttered that more than 4.83 million people are affected by flooding every year. Annual flooding also leads to around RM915 million loses in Malaysia. Due to the severity of flooding in Malaysia, there is a need to improve flood risk management especially in terms of flood vulnerability assessment.

Vulnerability is the degree of loss to a given set of elements at risk caused by flood event [2]. Flood vulnerability can also be described as an essential part of hazards and risk research which refers to the susceptibility of people, communities or regions to natural hazards [3]. It can be measured from various view like social, economic, physical, environmental, ecological, cultural and infrastructure components [4-6].

The four main vulnerability components of FVI used by many researchers are namely social, economic, infrastructure and physical vulnerability. Social vulnerability focuses on the reaction, response and resistance of population to flooding events. The criteria discussed in the literature include, gender, age, race, ethnicity, economic status, education, social status and unemployed [7-8]. Previous studies identified property values, land use classification and local economic structural assessment as major criteria for economic vulnerability [9]. Infrastructure components such as road networks, railways and road bridges are important to movement of population, communication and safety. The physical component of flood vulnerability are information about exposed elements (proximity to river, location or closeness to flood plain) [10]. Generally, area which are located near the main river have higher risk and more vulnerable to flooding [11].

Although there are various methods used by different authors to calculate FVI, the vulnerability index system is the most widely used method in many flood vulnerable studies. This method depends on complicated indices and weighting of their subjective. Eighty per cent (80%) of data used by decision maker are geographically related and integrate GIS with MCDM techniques [12]. Each of the criteria has to be associated with sub-criteria class.

Based on the input from decision makers, all the criteria and sub-criteria should be ranked and standardized score should be calculated. It is not easy to assess the flood vulnerability index because the concept is quite complex. Constructing a vulnerability index raises constraints such as to decide the assigned weights of criteria and standardized score of each sub-criterion. Different decision makers may apply different criteria and assign different weights for each criterion according to their preferences.

Flood vulnerability using weights from each criteria and sub-criteria can later be developed. All of the criteria and sub-criteria will be represented in the overlaying and spatial analysis process. Integration with GIS allow user to manage spatial data, attribute data and also to generate flood vulnerability maps [13-14]. In Malaysia, the combination of GIS and MCDM are also widely used in other environmental issue such as analysis for up-land agroforestry [15].

The aim of this study is to explore the potential integration between GIS and MCDM to undertake flood vulnerability index study in Kedah, Malaysia. Based on previous studies and expert opinions, the flood vulnerability components were defined. From that, the flood vulnerability index maps can be generated using Rank Sum and AHP methods.

II. Methodology

Basically the methodology adopted for this study is divided into four phases i) preliminary study, ii) data collection and iii) data interpretation and data processing and v) data analysis to evaluate flood vulnerable areas based on flood vulnerability index component. The preliminary study involves the selection of study areas and identification of flood vulnerability components to be used. Figure 1 shows the methodology flowchart adopted for this study.

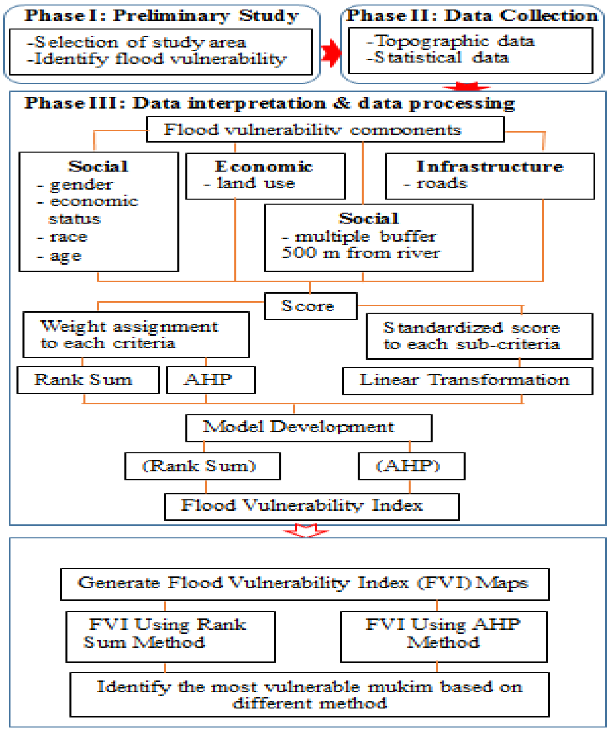

Figure 1: Methodology flowchart

A. Preliminary Study

Kedah State is situated in the northwest of Peninsular Malaysia within latitudes 5° 5' to 6° 35' North and longtitude 99° 40' to 101° 8' East. It covers an area of approximately 942,600 hectares. For this study, only 26 mukim within four (4) districts of Kota Setar, Kubang Pasu, Padang Terap and Pokok Sena were considered (refer to Appendix). The four main rivers within these districts which contribute to major flooding in 2010 are Pedu River, Padang Sanai River and Anak Bukit River.

B. Data Collection

The base map data were acquired from the Town and Planning Department and the Department of Survey and Mapping Malaysia (JUPEM). The data include the Kedah state district/mukim boundaries and digital topographic maps. The socio-economic data were obtained from the Department of Statistics Malaysia. The road networks and rivers were extracted from digital topographic maps acquired from JUPEM using the ArcGIS software. Land use map was generated from Landsat 5 Thematic Mapper (TM) image of 2010. The supervised classification technique was used to generate the land use map**.**

C. Data Interpretation and Processing

For this study rank sum and AHP methods were used to calculate the weight of the flood vulnerability components. The linear transformation technique was used to determine the weights for each sub-criteria.

Every criteria under consideration are ranked in the order of the decision maker's preference. To generate the criteria values, each of the criteria are weighted according to the estimated significance for causing flooding. The straight ranking (the most important =1, second important =2, etc) was applied in this research (refer to Table 1). As an example, if gender is ranked as 3, the normalized weight value is calculated by dividing the weight (i.e. 2) with total values of weight (i.e. 10) which gives the value of 0.2.

Table 1
Weight using Rank Sum Method

Component	Criteria	Rank	Weight	Normalized Weight
Soc	Gender	3	2	0.2
	Economic Status	1	4	0.4
	Race	4	1	0.1
	Age	2	3	0.3
Eco	Land use	1	1	1
Infra	Road	1	1	1
Phy(multiple buffer 500 m from river)	River	1	1	1

The AHP method uses the matrix calculation where the value of normalized weight is obtained from dividing the score value with the column total as shown in Table 2. For example, the physical multiple buffer 500 m (Phy500) area is less important than the economic component and the score value is 0.50. After calculation is completed, the sum of each row is obtained, i.e. the column total for physical multiple buffer of 500 m is 3.750. Then, each of the rows for each criterion will be summed. The weight value for each criterion is determined by the process of dividing the row sum with the total row sum.

Table 2
Weight using AHP Method

Criteria	Phy5	Eco	Infra	Soc	Weight
Phy	1.00	0.50	2.00	2.00	0.318
Eco	0.25	1.00	0.25	0.50	0.116
Infra	0.50	0.50	1.00	3.00	0.251
Soc	2.00	2.00	0.25	1.00	0.315
Total	3.750	4.000	3.500	6.500	1.00

D. Mathematical Calculation of Flood Vulnerability Assessment Model Based on Rank Sum and AHP

As mentioned earlier, this paper focused in four flood vulnerability components. Based on these vulnerability components eight models were developed. Models 1 to 4 are based on rank sum method. For the first models, four criteria (i.e. age, gender, race and socio-economic status) are used. The flood vulnerability model based on social component is given in Equation 1.

$$\text{Model 1} = (0.2*Stand\_Gender) + 0.4*Stand\_EcoStat) + (0.1*Stand\_Race) + (0.3*Stand\_Age) \quad (1)$$

where Stand_Gender is standardized score for gender sub-criteria, Stand_EcoStat is standardized score for socio-economic sub-criteria, Stand_Race is standardized score for race sub-criteria and Stand_Age is standardized score for age sub-criteria.

The second model use only one criteria (road proximity) and the derived model is given in Equation 2.

$$Model\ 2 = (1*Stand\_Rd) \tag{2}$$

where Stand_Rd is standardized score for road sub-criteria.

The third model also uses only one criterion (i.e type of land use) and the derived model is given in Equation 3.

$$Model\ 3 = (1*Stand\_Lu) \tag{3}$$

where Stand_Lu is standardized score for land use sub-criteria.

The last model in the Rank Sum method use one criterion (river proximity) and the derived model are given in Equation 4.

$$Model\ 4 = (1*Stand\_Riv) \tag{4}$$

where Stand_Riv is standardized score for river sub-criteria.

AHP method is used to develop models 5 to 8. For the first model (Model 5), four criteria (age, gender, race and socio-economic status) are used. The flood vulnerability model is given in Equation 5.

$$\begin{aligned} Model\ 5 = {} & (0.254*Stand\_Gender) + \\ & (0.2*Stand\_EcoStat\ ) + \\ & (0.125*Stand\_Race) + (0.352*Stand\_Age) \end{aligned} \tag{5}$$

The next model (Model 6) uses only one criterion (road proximity) and the derived model is given in Equation 6.

$$Model\ 6 = (1*Stand\_Road) \tag{6}$$

where Stand_Road is the standardized score for road sub-criterion.

Another model (Model 7) also use only one criterion (i.e. type of land use) and the derived model is given in Equation 7.

$$Model\ 7 = (1*Stand\_Lu) \tag{7}$$

where Stand_Lu is standardized score for land use sub-criteria.

The last model (Model 8) use one criterion (river proximity) and the derived model is given in Equation 8.

$$Model\ 8 = (1*Stand\_River) \tag{8}$$

where Stand_Riv is standardized score for river sub-criteria.

E. Mathematical Calculation of Flood Vulnerability Index

After calculating the economic, infrastructure, physical and social vulnerabilities, a Flood Vulnerability Index (FVI) was then calculated. The total value calculated for all aggregated components and each criteria is now contained in the respective raster and the FVI component is calculated using Equation 9.

$$FVI = (SocVul)+(EconVul) + (InfraVul)+(\ PhyVul) \tag{9}$$

where, SocVul is the social vulnerability, EconVul is economic the vulnerability, InfraVul is the infrastructure vulnerability and PhyVul is the physical vulnerability values.

III. RESULTS AND ANALYSIS

The results of this study are presented in three (3) sections. First section presents the flood vulnerability assessment maps based on both the MCDM techniques. The next section discusses the output from Flood Vulnerability Index maps generated from both MCDM techniques. The final section statistically compares the acreage of high risk areas of the eight most vulnerable areas within the study area.

A. Flood Vulnerability Assessment (FVA) Model Map Based on Different Vulnerability Models

Figure 2 shows the flood vulnerability model maps based on social, economic, infrastructure and physical components using Rank Sum method.

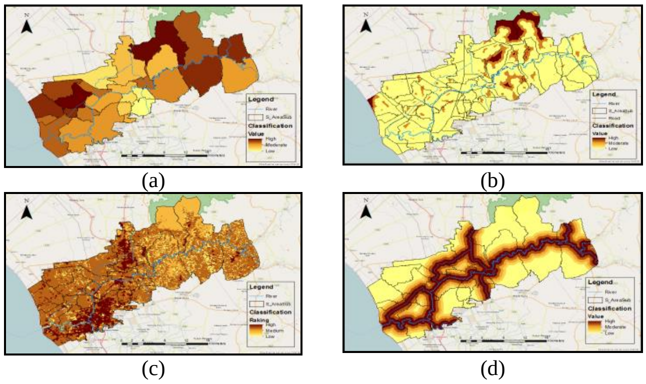

Figure 2; FVA model maps using Rank Sum method for (a) Social (b) Infrastructure (c) Economic and (d) Physical Vulnerabilities

The flood vulnerability model based maps generated based on social, economic, infrastructure and physical components using the AHP method is shown in Figure 3.

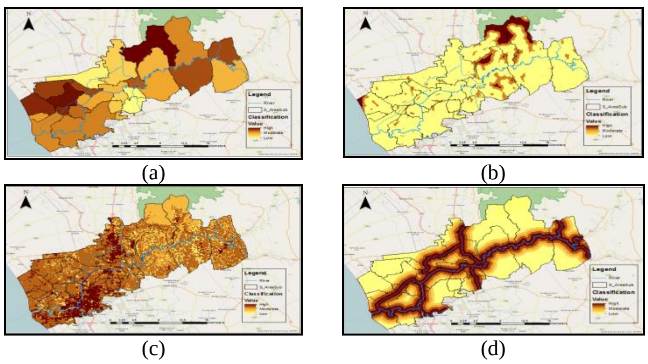

Figure 3: FVA model maps using AHP method for (a) Social (b) Infrastructure (c) Economic and (d) Physical Vulnerabilities

B. Flood Vulnerability Index Based on Rank Sum and AHP Method

Figure 4 shows the final FVI map, created by overlaying all of individual component layers based on Rank Sum and AHP method. The result shows the higher vulnerability areas are mainly located along rivers for all of four districts method, but it is different area (ha) value which vulnerable based on both of the method.

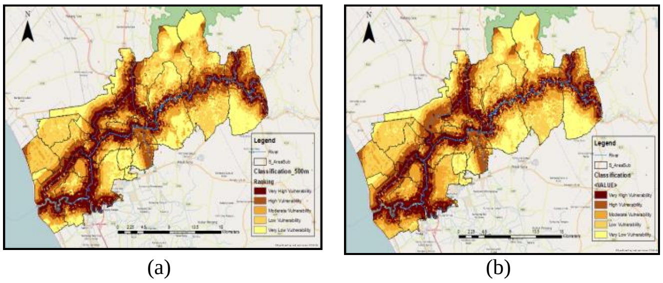

Figure 4: Flood Vulnerability Index maps using(a) Rank Sum (b) AHP

The flood vulnerability index interpretation is as shown in Table 3. The index value of 0.64-0.79 is categorized as veryhigh vulnerability, 0.51-0.63 is categorized as high vulnerability, 0.46-0.50 is categorized as moderate vulnerability, while the index value of 0.44-0.45 and 0.23-0.43 are categorized as low and very low vulnerabilities respectively.

Table 3
Flood vulnerability Index interpretation

Index Value	Description
0.64 – 0.79	Very High Vulnerability (VHV)
0.51 – 0.63	High Vulnerability (HV)
0.46 – 0.50	Moderate Vulnerability (MV)
0.44 – 0.45	Low Vulnerability (LV)
0.23 – 0.43	Very Low Vulnerability (VLV)

When the final flood index vulnerability is obtained, the area of flood vulnerable areas for each mukim are calculated based on FVI interpretation (refer to Table 3). Figure 5 shows the acreage of different vulnerability levels of the Kota Setar District (most vulnerable district). Using the Rank Sum method 2500 hectares of Kota Setar are considered as Very High Vulnerability (VHV) areas. The total acreage for High Vulnerability (HV), Moderate Vulnerability (MV), Low Vulnerability (LV) and Very Low Vulnerability (VLV) are 1090.05, 1311.11, 1189.76 and 856.83 hectares respectively. Using the AHP method the total area of the Kota Setar within VHV is also more than 2500. The total acreage for High Vulnerability (HV), Moderate Vulnerability (MV), Low Vulnerability (LV) and Very Low Vulnerability (VLV) are 946.40, 1088.3, 1622.40 and 809.50 hectares respectively.

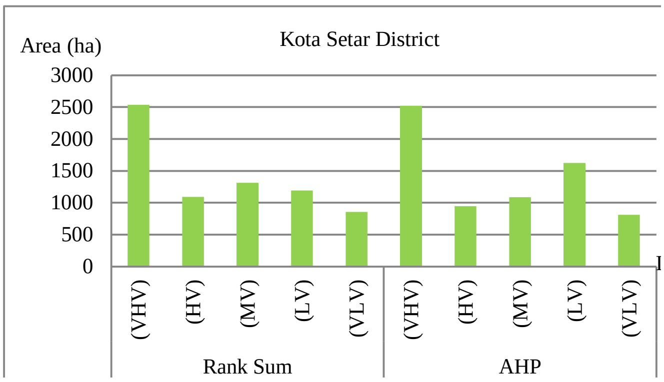

Figure 5: Acreage (in ha) of FVI using Rank Sum and AHP Methods of Kota Setar

C. Comparison of Top 8 Most Vulnerable Mukim within the Study Area using Different MCDM

Figure 6(a) shows the top 8 most vulnerable mukim based on the rank sum method. The most vulnerable mukim is Kota Setar, followed by Malau, Belimbing, Belimbing Kanan, Jitra, Derang, Kuala Kedah, Anak Bukit and Padang Lalang. The top 8 most vulnerable mukim using AHP method is shown in Figure 6(b). The most vulnerable mukim is also Kota Setar, followed by Malau, Derang, Belimbing Kanan, Jitra, Kuala Kedah, Anak Bukit and Padang Lalang. Slight changes in the mukim ranking (most vulnerable) can be observed when different techniques were used.

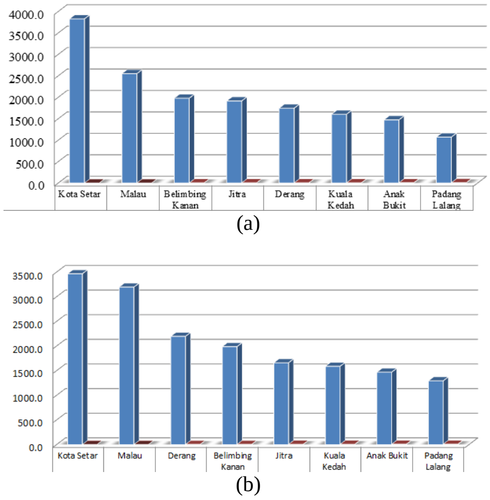

Figure 6: Top 8 most vulnerable mukim based on (a) Rank Sum (b) AHP

IV. Conclusion

This study presents the methodology and technique used to assess and map the flood vulnerable areas within the study area. Four different components of flood vulnerability were used, which are physical, economic, infrastructure and social. Two different MCDM techniques Rank Sum and AHP were used to calculate weights of the criteria. GIS is used to model and map the FVI. The vulnerability components are combined to determine the overall vulnerability index. The FVI is a powerful tool for mapping areas vulnerable to flooding which is crucial for future development or redevelopments. With the FVI tools, the impacts of flooding can be predicted based on different scenarios. It can help the decision makers and government flood related agencies for efficient flood risk management.

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APPENDIX

Description of the 26 Mukim in Study Area

Mu_ID	Mukim	Area (ha)
M1	LENGKUAS	775.71
M2	TELAGA MAS	1176.24
M3	LEPAI	692.9
M4	KUBANG ROTAN	532.35
M5	PADANG LALANG	2256.15
M6	SUNGAI BAHARU	481.65
M7	TITI GAJAH	890.63
M8	GUNONG	1997.58
M9	KOTA SETAR	6986.46
M10	ANAK BUKIT	1855.62
M11	ALOR MERAH	978.51
M12	BUKIT PINANG	611.78
M13	KUALA KEDAH	3200.86
M14	LANGGAR	268.71
M15	PADANG HANG	2202.07
M16	MALAU	4943.25
M17	WANG TEPUS	2742.87
M18	PELUBANG	829.79
M19	BUKIT TINGGI	951.47
M20	JITRA	4368.65
M21	NAGA	3143.4
M22	KURONG HITAM	4963.53
M23	BELIMBING KIRI	2540.07
M24	PADANG TEMAK	4478.5
M25	BELIMBING KANAN	4301.05
M26	DERANG	3836.3

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